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DESCRIPTION

MECHANICAL COMPONENT AND

METHOD OF FABRICATING THE SAME

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TECHNICAL FIELD

The present invention relates to a mechanical component composed of a steel and surface-hardened by nitriding, and a method of fabricating the same, and in more detail, relates to a mechanical

10   component which is surface-hardened and, at the same time, imparted both with strength and bending straightening property, and a method of fabricating the same.

BACKGROUND ART

15   There are high levels of demands on wear resistance and fatigue property for mechanical components such as gear, bearing, shaft, crank shaft and connecting rod.   Fabrication of these mechanical components generally involves surface hardening for raising strength such as wear resistance and fatigue property.   The surface hardening is typically

20   carried out after a material to be forged composed of a carbon steel or an alloyed steel for manufacturing mechanical structures is hot-forged, annealed typically for normalizing, and further machined into a predetermined geometry desired for various mechanical components. After the surface hardening, the material is finished typically through

25   bend straightening, to thereby given as a final product of the mechanical

component.

The surface hardening is carried out by nitriding such as salt bath nitriding and gas soft nitriding. It is generally known that the nitriding causes only a small post-processing distortion as compared with that

5 possibly occurs after surface hardening such as cementation, and is recognized as a particularly effective method (as found in Japanese Laid-Open Patent Publication "Tokkaihei" No. 09-324258, for example).

The surface hardening through nitriding may, however in some cases, result in an unallowable level of generated distortion, and as a

10 consequence often needs bend straightening after the surface hardening. The bend straightening is carried out so as to straighten the bend to a level allowable by the product, wherein easiness of the process, or bend straightening property depends on the surface hardness achieved after the surface hardening. The lower the surface

15 hardness becomes, the bend straightening property improves. On the other hand, the lower the surface hardness becomes, the component strength such as wear resistance and fatigue property of the mechanical components degrades. Larger surface hardness is therefore preferable for the purpose of raising component strength of the mechanical

20 components. As is known from the above, it is preferable to sufficiently raise the surface hardness by the surface hardening from the viewpoint of component strength of the mechanical components, and it is preferable to suppress as possible the surface hardness achieved by the surface hardening from the viewpoint of bend straightening property,

25 because a larger surface hardness will degrade the bend straightening

property and will be more likely to cause micro-cracks on the surface during the bend straightening.

As described in the above, it is not easy for the mechanical components to harmonize excellent component strength and bend straightening property after being surface-hardened. It is, however, a critical issue to carry out the surface hardening in order to ensure desirable quality of the fabricated mechanical components and to improve the yield ratio of the products, and to improve the component strength and bend straightening property of the mechanical components provided as the products after the surface hardening. The present invention is indeed conceived after considering the above-described problems, and an object thereof resides in providing a mechanical component and a method of fabricating the same, which involve surface hardening by nitriding, and are capable of improving both of component strength and bend straightening property.

DISCLOSURE OF THE INVENTION

A mechanical component aimed at solving the above-described problems is composed of a steel and surface-hardened by nitriding, having a Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of the mechanical component of 340 to 460 HV, having a Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness of 190 to 260 HV, and having an effective depth of hardened layer measured from the component surface, where a

Vickers hardness of 270 HV is achieved, of 0.3 mm or more.

A method of fabricating a mechanical component aimed at solving the above-described problems is a method of fabricating a mechanical component composed of a steel and surface-hardened by nitriding,

wherein the nitriding is carried out so as to adjust Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of the mechanical component to 340 to 460 HV, so as to adjust Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness to 190 to 260 HV, and so as to adjust an effective depth of hardened layer measured from the component surface, where a Vickers hardness of 270 HV is achieved, to 0.3 mm or more.

The above-described mechanical component is targeted at those composed of a steel and surface-hardened by nitriding. The nitriding is a treatment allowing nitrogen component to diffuse from the surface towards the inner portion of the mechanical component so as to nitrify the surficial portion of the mechanical component, to thereby raise the hardness of the surficial portion including the component surface. An essential point in the present invention is not only to improve the surface hardness by nitriding, but also to impart the mechanical component, to be provided after the treatment as the product, both with an excellent component strength and bend straightening property. The foregoing paragraphs have already discussed that the surface hardness of the surficial portion of the mechanical component can be improved by the

nitriding. Increase in the surface hardness results in increase in the component strength of the mechanical components such as wear resistance and fatigue property. On the other hand, increase in the surface hardness results in decrease in the bend straightening property

5   which indicates degree of process easiness in the bend straightening carried out after the nitriding. The decrease in the bend straightening property results in generation of nonconformities such as micro-cracks in the component surface, and this fails in product making of desirable mechanical components, and is causative of a lowered yield ratio of the

10   products in the manufacturing.

As described in the above, carrying-out of the nitriding and achievement of excellent component strength and bend straightening property of the mechanical products seem to result in an inevitable dilemma so far as the treatment is to be conducted. The present

15   inventors, however, derived a conclusion after extensive experiments and discussion that both of excellent strength and bend straightening property can be imparted to the mechanical components even after nitriding, by optimizing a hardness distribution to be imparted by the nitriding in the depth-wise direction from the component surface, or in

20   other words, by optimizing a hardness distribution in the depth-wise direction in the surficial portion of the mechanical component to be provided as the product after nitriding, and by optimizing hardness of the inner portion not affected by the nitriding and showing a nearly constant hardness.

25   The mechanical component of the present invention is therefore

such as being surface-hardened by nitriding, and having a Vickers hardness of the surficial portion measured at a reference position corresponded to a 50 μm depth from the surface of the mechanical component (referred to as "surficial reference position", hereinafter) of

5 340 to 460 HV, having a Vickers hardness of the inner portion being not affected by the nitriding and showing a nearly constant hardness (simply referred to as "inner portion", hereinafter) of 190 to 260 HV, and having an effective depth of hardened layer measured from the component surface, where a Vickers hardness of 270 HV is achieved, of 0.3 mm or

10 more.

First, a Vickers hardness at the surficial reference position of less than 340 HV may result in only a small surface hardness, and may fail in making the component useful and excellent in the component strength. On the other hand, a Vickers hardness exceeding 460 HV

15 may result in a large surface hardness, may become more likely to induce nonconformities such as causing micro-cracks during bend straightening, and may fail in making the component useful and excellent in the bend straightening property. Next, a Vickers hardness of the inner portion of less than 190 HV may fail in imparting a desired

20 hardness up to a position of a sufficient depth from the component surface, even if the component is subjected to the nitriding so as to adjust the Vickers hardness at the surficial reference position to a desirable range, and this consequently results in only a small surface hardness, and may fail in making the component useful and excellent in

25 the component strength. On the other hand, a Vickers hardness of the

inner portion exceeding 260 HV may result in an excessive increase in the hardness of the surficial portion imparted by the nitriding, even if the component is subjected to the nitriding so as to adjust the Vickers hardness at the surficial reference position to a desirable range, and this

5   makes an amount of increase in the hardness of the surficial portion too large, and consequently results in a large surface hardness, and may fail in making the component useful and excellent in the bend straightening property.

During diffusion of nitrogen component in the depth-wise

10   direction from the component surface, diffusion concentration of the nitrogen component decreases in the increasing direction of depth, and reaches the inner portion which is not affected by the nitriding and therefore shows an almost constant hardness, and this indicates an end of the diffusion of the nitrogen component.   In other words, the amount

15   of increase in the hardness given by the nitriding decreases in the increasing direction of depth from the component surface towards the inner portion.   The rate of decrease in the amount of increase in the hardness can arbitrarily vary depending on species and contents of constituent elements of the steel composing the mechanical components,

20   and on temperature and process time of the nitriding.   It is therefore insufficient to optimize the hardness distribution in the depth-wise direction in the surficial portion after the nitriding only by specifying ranges for the surficial reference position and hardness of the inner portion.   Therefore the mechanical component of the present invention

25   is further given with a condition describing that the effective depth of

hardened layer (also simply referred to as "effective hardening depth",

hereinafter) measured from the component surface, where a Vickers

hardness of 270 HV is achieved, is adjusted to 0.3 mm or more.   This

condition means moderation of the rate of decrease in the amount of

5   increase in the hardness given by the nitriding, which occurs so as to

decrease in the depth-wise direction from the component surface

towards the inner portion, and this consequently makes it possible to

provide the surficial portion of the mechanical component after the

nitriding with a larger hardness over a range from the component

10   surface towards a deeper position.   More specifically, an effective

depth of hardening from the component surface, where a Vickers

hardness of 270 HV is achieved, of less than 0.3 mm may result in a too

sharp decrease in the hardness distribution in the depth-wise direction

in the surficial portion of the mechanical component, and may

15   sometimes fail in obtaining the surface hardness necessary for making

the component useful and excellent in the strength.

As described in the above, the mechanical component can be

made excellent both in the strength and bend straightening property, by

appropriately specifying hardness at the surficial reference position,

20   hardness of the inner portion and effective hardening depth, and by

optimizing hardness distribution in the depth-wise direction from the

component surface.

The mechanical component can adopt various steels as a

material composing thereof depending on field of application.

25   Therefore in the method of fabrication, it is made possible to adjust the

surficial reference position, hardness of the inner portion and effective

hardening depth within the above-described ranges, and to make the

mechanical component excellent both in the strength and bend

straightening property, by adjusting flow rate of nitrogen component over

5   the surface of the component, temperature and process time of the

nitriding, in a manner appropriately adapted to composition of a steel

composing the component.

Next, the mechanical component of the present invention is

characterized by having compositions of the individual constituent

10   elements adjusted so as to limit Cr[eq.] to 0.72% or more and 1.0% or

less, and C[eq.] to 0.65% or more and 0.86% or less, under definitions of

Cr[eq.]=0.475×C+0.164×Si+0.241×Mn+Cr and

C[eq.]=C+0.07×Si+0.16×Mn+0.19×Cu+0.17×Ni+0.2×Cr, and

having a hardness distribution profile H(x), which is given by

15   plotting, on the H-x plane, Vickers hardness H measured in the

depth-wise direction x as viewed from the component surface, fallen in

region Z expressed by the equation (1) below:

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - erf\left(\frac{x}{2\sqrt{\alpha Dt}} \right) \right] \quad \cdots(1)$$

20   where,

H'0=C[eq.]×254+33.8

H'1=Cr[eq.]×392+65.8

Cr[eq.]: chromium equivalence described in the above

C[eq.]: carbon equivalence described in the above;

25    $$D = D_0 \times exp\left(\frac{-Q}{R \times (T + 273)} \right)$$

D_0: 1.13×10^{-6}

$$Q : 83 \times \left(1 - \frac{14.03}{T+273}\right) \times 1000$$

R: 8.314;

α=exp(-1.47×Si-0.918×Mn+0.998)

Si : Si content (wt%)

Mn: Mn content (wt%); and

region Z is defined as a region in which H'(x) expressed by the equation (1) can move on the H-x plane while satisfying a condition of H'(0.3×10^{-3})$\geqq$270, when t varies from 3.6×10^3 to 18×10^3 and T varies from 500 to 650.

In the nitriding, degree of hardening of the surficial layer is affected by composition of a steel material composing the mechanical component. For the purpose of making hardness at the surficial reference position, hardness of the inner portion and effective hardening depth fall within the above-specified ranges in a more reliable manner, an effective method may be such as optimizing steel composition effectively contributable to hardness of the inner portion corresponded to the hardness of the surficial portion before the nitriding, and steel composition effectively contributable to the nitriding. For this purpose, first in the steel material for composing the mechanical component, chromium equivalence Cr[eq.], defined as Cr[eq.]=0.475×C+0.164×Si+0.241×Mn+Cr, is adjusted to 0.72% or more and 1.0% or less in % by weight. The Cr[eq.] herein is understood as

an index of compositional components capable of effectively raising hardness at the surficial reference position.   Compositional components capable of effectively raising hardness at the surficial reference position of the mechanical component after the nitriding were

5   found to be Cr, C, Mn and Si, enumerated in a decreasing order of the effect.   The constant terms expressing degrees of such effect are measured values determined by extensive measurements.   A value of thus-defined Cr[eq.] of less than 0.72% may sometimes fail in raising Vickers hardness at the surficial reference position of the mechanical

10   component to as high as 340 HV or more even after the nitriding, and on the other hand, a value of Cr[eq.] exceeding 1.0% may sometimes fail in suppressing Vickers hardness at the surficial reference position of the mechanical component to as low as 460 HV or less due to an excessive hardening of the surficial portion during the nitriding.

15   Next, in the steel material for composing the mechanical component, carbon equivalence C[eq.], defined as C[eq.]=C+0.07×Si+0.16×Mn+0.19×Cu+0.17×Ni+0.2×Cr, is adjusted to 0.65% or more and 0.86% or less in % by weight.   The C[eq.] herein is understood as an index of compositional components capable of

20   effectively raising hardness of the inner portion.   Compositional components capable of effectively raising hardness of the inner portion of the mechanical component were found to be C, Cr, Cu, Ni, Mn and Si, enumerated in a decreasing order of the effect.   The constant terms expressing degrees of such effect are values determined by extensive

25   measurements, similarly to as described in the above.   A value of

thus-defined C[eq.] of less than 0.65% may sometimes fail in raising

Vickers hardness of the inner portion of the mechanical component to as

high as 190 HV or more, and on the other hand, a value of C[eq.]

exceeding 0.86% may sometimes fail in suppressing Vickers hardness

5   of the inner portion of the mechanical component to as low as 260 HV or

less due to an excessive hardening of the inner portion.

The mechanical component is also characterized by having a

hardness distribution profile H(x), which is given by plotting, on the H-x

plane, Vickers hardness H measured in the depth-wise direction x as

10   viewed from the component surface, fallen in region Z expressed by the

equation (1) below:

$$H'(x) = H'0 + (H'1 - H'0) \times \left[1 - erf\left(\frac{x}{2\sqrt{\alpha Dt}}\right)\right] \quad \cdots(1)$$

where,

15   H'0=C[eq.]×254+33.8

H'1=Cr[eq.]×392+65.8

Cr[eq.]: chromium equivalence described in the above

C[eq.]: carbon equivalence described in the above;

$$D = D_0 \times exp\left(\frac{-Q}{R \times (T + 273)}\right)$$

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D_0: 1.13×10^{-6}

$$Q : 83 \times \left(1 - \frac{14.03}{T + 273}\right) \times 1000$$

R: 8.314;

25     $\alpha = exp(-1.47 \times Si - 0.918 \times Mn + 0.998)$

Si : Si content (wt%)

Mn: Mn content (wt%); and

region Z is defined as a region in which H'(x) expressed by the

equation (1) can move on the H-x plane while satisfying a condition of

5    $H'(0.3 \times 10^{-3}) \geqq 270$, when t varies from 3.6×10^3 to 18×10^3 and T varies

from 500 to 650.

The nitriding is a treatment allowing nitrogen component to

diffuse in the depth-wise direction from the component surface.

Diffusion equation C(x) expressing diffusion concentration C of the

10   nitrogen component with respect to the depth-wise direction x can

generally be given by the equation (2) below:

$$C(x) = C0 + (C1 - C0) \times \left[1 - erf\left(\frac{x}{2\sqrt{Dt}} \right) \right] \quad \cdots (2)$$

where,

15   D: dffusion coefficient and

t: time elapsed from start of diffusion

According to the equation (2), and assuming now that concentration of

the nitrogen component in a region of x>0 (x=0 is the surface of the

component, and the depth-wise direction x as viewed from the

20   component surface defined as positive) at time t=0 (start time of the

nitriding) as C0 (C0=0 in this nitriding), C(0) at x=0 is understood as an

equation expressing changes in diffusion concentration of the nitrogen

component in the depth-wise direction x as viewed from the surface

(x=0) of the component, assuming that the surface of the component

25   always has a constant nitrogen component concentration C1.   A basic

.concept of the present invention is to adopt the equation in an approximated manner, so as to optimize the hardness distribution in the depth-wise direction in the surficial portion of the mechanical component.

5   The nitriding is a treatment allowing nitrogen component to diffuse in the depth-wise direction from the component surface so as to harden the surficial portion through nitriding.   Diffusion concentration of the nitrogen component at a certain depth from the component surface is, therefore, closely related to a degree of hardness attained at the depth

10   by the nitriding, and allows an approximated substitution.   First, $C(x)$ in the equation (2) is substituted by hardness distribution $H'(x)$ in the depth-wise direction x as viewed from the component surface after the nitriding.   Next, C0 in the equation (2) is substituted by H'0 expressing hardness of the inner portion of the mechanical component, that is,

15   hardness of the surficial portion at the start time of the nitriding is assumed as hardness of the inner portion.   H'0 is further defined as $H'0 = C[eq.] \times 254 + 33.8$, to which, together with C[eq.], a measured value based on results of hardness measurement is adopted.   Next, C1 in the equation (2) is substituted by H'1 expressing hardness at the surficial

20   reference position of the mechanical component, wherein H'1 is supposed to have a value expressing hardness at the surficial reference position of the mechanical component because the hardness of the true surface of the mechanical component cannot be measured.   H'1 is further defined as $H'1 = Cr[eq.] \times 392 + 65.8$, to which, together with Cr[eq.],

25   a measured value based on results of hardness measurement is

adopted.   This mode of approximated use of the equation (2) gives the equation (1).

D in the equation (1) is a diffusion coefficient in metal or alloy, and is generally expressed as $D=D_0 \times \exp(-Q/(R \times (T+273)))$, where D_0 is a

5   term of number of vibration frequency, Q is activation energy, R is the gas constant, and T is temperature in degrees centigrade.   In the present invention, diffusion coefficient D was determined assuming that nitrogen as a diffusing element diffuses in a pure Fe, because the mechanical component is composed of a steel, and content of a major

10   component Fe contained therein is supposed to be at least 50 wt% or more. Specific values adopted herein are values described in a literature (Metal Data Book, 3rd Edition, published by Maruzen; p.21), defined for the case where N as a diffusing element diffuses in α-δ-Fe, which are $D_0=1.13 \times 10^{-6}$, $Q=83 \times (1-14.03/(T+273)) \times 1000$ and $R=8.314$.

15   Next, α in the equation (1), not found in the equation (2), is a correction diffusion coefficient correcting diffusion coefficient D used in the equation (1).   The correction diffusion coefficient α herein was defined as $\alpha=\exp(-1.47 \times Si-0.918 \times Mn+0.998)$.   The correction diffusion coefficient α is used for incorporating any influences of constituent

20   elements other than Fe contained in the steel exerted on the diffusion of N into H'(x).   Again α is a measured value based on results of extensive hardness measurement.   What is worth attracting an attention is that Si and Mn contained in the steel, in particular Si, are constituent elements suppressing the diffusion of N.   In other words, α sharply decreases as

25   the contents of Si and Mn increase.   Optimization of the Si content is,

therefore, understood as one essential point in reliably optimizing the hardness distribution in the depth-wise direction of the surficial portion of the mechanical component. It is preferable to adjust the Si and Mn contents so as to make α fall within a range from 0.3 to 1.6, for example.

5   In H'(x), t represents process time of the nitriding, and a value thereof generally falls within a range from 3.6×10^3 to 18×10^3 seconds. T represents process temperature of the nitriding, and a value thereof generally falls within a range from 500 to 650°C.

H'(x) is determined as described in the above. The H'(x) is a

10   function having arbitrary variables of t and T with respect to process conditions of the nitriding, given when a composition of the steel used for composing the mechanical component is uniquely determined. Hardness distribution profile, which is obtained by plotting, on the H-x plane, Vickers hardness H measured in the depth-wise direction x as

15   viewed from the component surface, is now given as H(x). H(x) is restricted to reside only in region Z, wherein the region Z is defined as a region in which H'(x) can move on the H-x plane when t is arbitrarily varied from 3.6×10^3 to 18×10^3 and T is arbitrarily varied from 500 to 650, while satisfying a condition that a Vickers hardness of 270 HV is attained

20   at a depth from the component surface of 0.3 mm or more, or in other words, under a condition that a position of 0.3 mm deep from the component surface will show a hardness of 270 HV or more as expressed by $H'(0.3 \times 10^{-3}) \geqq 270$. A region of the hardness distribution H(x) as viewed from the surface of the mechanical component restricted

25   to as described in the above makes it possible to reliably optimize the

hardness distribution in the depth-wise direction in the surficial portion of the mechanical component, and to impart both of excellent component strength and bend straightening property to the mechanical component. The region of H(x) restricted herein in the region Z means that all

5 requirements on the composition of the steel material for the mechanical component, such as Cr[eq.], C[eq.], Si content and Mn content, are optimized within ranges for general process conditions of the nitriding. This mode of optimization of the composition of the steel material makes it possible to more reliably impart excellent strength and bend

10 straightening property to the mechanical component.

In the method of fabrication, it is made possible to more reliably impart excellent strength and bend straightening property to the mechanical component, by adjusting the ranges of Cr[eq.] and C[eq.] to the ranges similar to those described in the above, and also by adjusting

15 the nitriding conditions to those described in the next. The nitriding conditions adopted to gas soft nitriding or salt bath nitriding include a process time of 3.6×10^3 to 18×10^3 seconds and nitriding temperature of 500 to 650°C. Other nitriding conditions adopted herein are same as those adopted by the general gas soft nitriding or salt bath nitriding. A

20 nitriding temperature of less than 500°C may sometimes excessively reduce the diffusion of the nitrogen component, and may consequently fail in imparting, by the nitriding, a desired profile of surface hardness in the depth-wise direction to the mechanical component. On the contrary, a nitriding temperature exceeding 650°C may excessively accelerate the

25 diffusion of the nitrogen component, and may sometimes excessively

raise the surface hardness than desired.   Next, as for the process time, a time less than 3.6×10^3 seconds, or one hour, may sometimes fail in imparting, by the nitriding, a desirable surface hardness profile in the depth-wise direction to the mechanical component.   On the contrary, a

5   process time of the nitriding exceeding 18×10^3 seconds, or five hours, may sometimes result in a too large surface hardness than desired. Ranges of the process time and process temperature of the nitriding are thus set in consideration of these situations, wherein these ranges can be said as more general ones than those set from viewpoints such as

10   operation efficiency in the manufacture.   The conditions for the nitriding are set based on these reasons, and this is consequently successful in imparting excellent strength and bend straightening property to the mechanical component in a more reliable manner.

Next, the mechanical component of the present invention is

15   characterized by having, in % by weight, an Fe content of 90% or more, and containing constituent elements with the individual contents of C: 0.35 to 0.5%, Si: 0.01 to 0.3%, Mn: 0.6 to 1.8%, Cu: 0.01 to 0.5%, Ni: 0.01 to 0.5%, Cr: 0.01 to 0.5%, Al: 0.001 to 0.01% and N: 0.005 to 0.025%.

20   The mechanical component of the present invention is composed of a steel material.   Major component thereof is therefore Fe as described in the above, and more specifically, the Fe content is adjusted to 90% or more by weight.   As one of the constituent elements other than Fe, C is contained in an amount of 0.35 to 0.5% by weight.   C is an

25   element useful for effectively raising the hardness in the inner portion

and at the surficial reference position of the mechanical component, wherein a content of 0.35% or more makes the effect more distinct. On the contrary, the content exceeding 0.5% may sometimes result in an excessive effect, and may fail in adjusting the hardness of the surficial

5   layer of the mechanical component to a desired level. It may also be causative of degradation in the machinability when the mechanical component is machined into a desired geometry, for example when a forged material composed of a steel is machined. Next, Si is contained in an amount of 0.01 to 0.3% by weight. Si is used as a deoxidizer

10 element in steel melting, so that it is necessarily contained at least in an amount of 0.01% or more. Si is, however, also a constituent element suppressing the N diffusion in the nitriding. In view of reliably imparting a desired hardness profile to the mechanical component, it is preferable to suppress the content thereof to as low as 0.3% or less. Next, Mn is

15 contained in an amount of 0.6 to 1.8% by weight. Mn is an element useful for effectively raising the hardness of the inner portion and at the surficial reference position, wherein a content of 0.6% or more makes the effect more distinct. On the contrary, the content exceeding 1.8% may sometimes result in generation of bainite during operations such as

20 hot forging and normalizing before the nitriding. Also Mn is a constituent element suppressing the N diffusion in the nitriding, although to a lesser degree as compared with Si. Also from this point of view, the content of Mn is preferably suppressed to as small as 1.8% or less.

Both of Cu and Ni are contained in an amount of 0.01 to 0.5% by

25 weight. Both of Cu and Ni are contained as inevitable impurities in an

amount of 0.01% or more, and are useful for effectively raising the

hardness of the inner portion of the mechanical component. The

content exceeding 0.5% may, however, be disadvantageous from an

economical point of view, and may raise cost of the mechanical

5   component, so that the content is adjusted to 0.5% or less. Next, Cr is

contained in an amount of 0.01 to 0.5% by weight. Cr is an element

useful for effectively raising the hardness of the inner portion and at the

surficial reference position of the mechanical component. The content

adjusted to 0.01% or more is successful in making the effect more

10   distinct. On the contrary, the content exceeding 0.5% may sometimes

result in an excessive effect, and may fail in adjusting the hardness of

the surficial layer of the mechanical component to a desired level. Next,

Al is contained in an amount of 0.001 to 0.01% by weight. Similarly to

Si, also Al is used as a deoxidizer element in steel melting, so that it is

15   necessarily contained at least in an amount of 0.001% or more.

However in some cases, Al may excessively raise the hardness at the

surficial reference position of the mechanical component, so that the

content thereof is preferably limited to 0.01% or less. Next, N is

contained in an amount of 0.005 to 0.025% by weight. N is an element

20   useful for effectively suppressing crystal grain growth of the steel

component typically during hot forging, through formation of nitride with

Al. The content thereof is preferably set to as much as 0.005% or more,

but a content of 0.025% may be enough for the upper limit thereof,

because the effect saturates above 0.025%.

25   The mechanical component of the present invention is

characterized by containing any one species, or two or more species of constituent elements with the individual contents, in % by weight, of Pb: 0.30% or less, S: 0.20% or less, Ca: 0.01% or less, Bi: 0.30% or less, Ti: 0.02 or less, Zr: 0.02% or less and Mg: 0.01% or less.

5   Pb, S, Ca and Bi described in the above are elements useful for effectively improving machinability when a forged material composed of a steel is machined into a desired geometry.   Without a desirable level of machinability, an excessive machining distortion or the like may generate on the surface of the component during machining, and may

10   fail in reliably imparting a desired level of bend straightening property to the mechanical component.   As for the individual contents of Pb, S, Ca and Bi, any contents exceeding the above-described upper limits may degrade the hot workability or component strength such as fatigue property of the mechanical component, so that it is preferable to adjust,

15   in % by weight, Pb to 0.30% or less, S to 0.20% or less, Ca to 0.01% or less and Bi to 0.30% or less.   Next, Ti, Zr and Mg are known to promote micro-dispersion of MnS and so forth in steel melting, through formation of their oxides.   The effect also makes it possible to improve the machinability in the machining, and to micronize a crystal texture of the

20   steel after annealing such as normalizing in the succeeding step of hot forging, for example, and further to reliably impart necessary component strength and bend straightening property to the mechanical component. As for the individual contents of Ti, Zr and Mg, any contents exceeding the above-described upper limits may saturate the effect, so that it is

25   preferable to adjust, in % by weight, Ti to 0.02% or less, Zr to 0.02% or

less, and Mg to 0.01% or less.

The foregoing paragraphs have described the essential points of the mechanical component of the present invention to which both of strength and bend straightening property should be imparted.

5   Mechanical component targeted at by the present invention is not specifically limited, and is applicable to any publicly-known mechanical components such as gear, bearing, shaft, crank shaft and connecting rod.   Among others, a special limitation is placed on crank shaft.   This is because the crank shaft is a mechanical component used under

10   high-speed rotation and needs a precise control of decentering by bend straightening.   The crank shaft can improve its usefulness by being applied with the mechanical component of the present invention which can be made excellent both in strength and bend straightening property.

15   BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic side elevation of one embodiment of the mechanical component of the present invention;

Fig. 2 is a sectional view taken along line II-II in Fig. 1; and

Fig. 3 is a drawing showing hardness profiles based on

20   measured results and theoretical calculation.

                    BEST MODES FOR CARRYING OUT THE INVENTION

The following paragraphs will explain a best embodiment of the mechanical component of the present invention referring to the attached

25   drawings.

Fig. 1 is a schematic side elevation of a fillet portion of one essential portion of a crank shaft, which is one embodiment of the mechanical component.   Fig. 2 is a schematic sectional view of the fillet portion taken along line II-II in Fig. 1.   In the drawing, the fillet portion 1

5   is understood as a mechanical component 1.   Because the crank shaft is formed by assembling separately-manufactured constituents, assumption of the fillet portion as the mechanical component of the present invention will never depart from the spirit of the present invention.   The fillet portion 1 is composed of a steel and is nitrided.

10   As shown in Fig. 2, the fillet portion 1 comprises a surficial portion 2 raised in the surface hardness by the nitriding, and an inner portion 3 not affected by the nitriding and showing a nearly constant hardness.   In the surficial portion 2, the hardness decreases in the depth-wise direction from a component surface 4 towards the inner portion 3.   The

15   inner portion 3 is adjusted to have a Vickers hardness of 190 to 260 HV, the surficial portion 2 is adjusted to have a Vickers hardness of 340 to 460 HV at the reference position corresponded to a 50 μm depth from the component surface, and is further adjusted to have an effective depth of hardened layer measured from the component surface 4, where

20   a Vickers hardness of 270 HV is achieved, of 0.3 mm or more.   This way of adjustment of the hardness distribution in the surficial portion 2 in the depth-wise direction from the component surface 4 makes it possible to improve component strength of the mechanical component 1, such as wear resistance and fatigue property, and to improve the bend

25   straightening property in bend straightening in the succeeding step of

the nitriding.

By imparting both of excellent strength and bend straightening property to the mechanical component as described in the above, it is made possible to effectively suppress generation of micro-cracks in
5   bend straightening, and to make the mechanical component excellent in the strength.

Next paragraphs will explain an exemplary method of fabricating the mechanical component of the present invention, including the fillet portion shown in Fig. 1.   First, a steel material having a predetermined
10   composition is prepared by melting so as to attain a steel composition necessary for the mechanical component, and is then hot-forged to yield a forged material.   The forged material composed of the steel is then thermally refined by annealing such as normalizing, quenching and tempering, and is machined according to a desired geometry of the
15   mechanical component.   After the machining, the mechanical component is subjected to surface hardening by nitriding to so as to improve the strength.   Next, bend straightening is carried out in order to make any bend, including those ascribable to distortion generated by the nitriding, fall within a desired allowable range.   After a series of such
20   manufacturing steps, the mechanical component is provided as a product.   For any mechanical components composed of two or more types of constituents manufactured in a separate manner, each of the constituents is assumed as the mechanical component, respectively manufactured according to the above-described process flow, and
25   assembled to thereby obtain the mechanical component of a desired

geometry. In this sense, the mechanical component of the present invention is essentially targeted at publicly-known mechanical components such as gear, bearing, shaft, crank shaft and connecting rod, but any of those composed of two or more constituents can be

5   assumed that each of the constituents is understood as the mechanical component of the present invention.

It is to be noted that the above-described fabrication method is only one example, and the present invention also allows a non-refining process from which the refining by annealing after hot forging is omitted.

10   An essential point is that any fabrication method can be adopted as the fabrication method so far as it involves at least surface hardening by nitriding, which is followed by bend straightening to thereby finish the mechanical component as a product. The nitriding may be carried out by publicly-known method such as salt bath nitriding and gas soft

15   nitriding. Appropriate adjustment of conditions for the nitriding, such as process temperature, process time and flow rate of nitrogen to be supplied to the component surface, makes it possible to achieve a desired depth-wise hardness distribution in the surficial portion of the mechanical component.

20   Next paragraphs will describe embodiments as confirmation of the effects of the present invention.

(Embodiment)

Steels having chemical compositions (in wt%) listed in Table 1

25   were melted, and hot-forged to thereby fabricate rod-formed forged

materials of 40 mm in diameter. The forged materials were then kept under heating at 880°C for 60 minutes, and then normalized by allowing them to cool down to room temperature. The forged materials were then machined into a geometry of the fillet portion of the crank shaft

5   shown in Fig. 1. The machined fillet portions were nitrided by gas soft nitriding. Conditions adopted herein include a process time of 2 hours $(7.2 \times 10^3$ seconds) and a process temperature of 600°C, which fall in general ranges. Thus-fabricated embodied products 1 to 10 and comparative products 1 to 12 were subjected to measurements shown

10   below. Table 1 shows also chromium equivalence Cr[eq.] and carbon equivalence C[eq.] of the individual steels composing the individual test pieces. Table 1 still also shows calculated results of $H'(0.3 \times 10^{-3})$, which are values of Vickers hardness at a 0.3 mm deep from the component surface based on the theoretical formula $H'(x)$ given as the

15   equation (1) in the above.

Table 1

	C	Si	Mn	Cu	Ni	Cr	Al	N	Others	Cr[eq.]	C[eq.]	H'(0.3×10³)
Embodied product 1	0.4	0.05	1.45	0.05	0.05	0.2	0.005	0.023		0.75	0.69	273
Embodied product 2	0.35	0.28	0.65	0.45	0.45	0.48	0.002	0.012		0.85	0.73	312
Embodied product 3	0.5	0.12	1.75	0.15	0.15	0.04	0.008	0.008		0.72	0.85	282
Embodied product 4	0.45	0.1	1.2	0.1	0.1	0.45	0.002	0.02		0.97	0.78	330
Embodied product 5	0.4	0.08	1.48	0.1	0.1	0.2	0.005	0.005	Pb:0.18, S:0.062	0.76	0.72	277
Embodied product 6	0.42	0.1	1.44	0.08	0.08	0.18	0.003	0.003	S:0.121, Ca:0.0025	0.74	0.72	275
Embodied product 7	0.41	0.12	1.45	0.1	0.1	0.21	0.004	0.004	Bi:0.1, S:0.052, Ca:0.0042	0.77	0.73	279
Embodied product 8	0.42	0.09	1.51	0.07	0.08	0.19	0.006	0.006	S:0.065, Ca:0.0026, Ti:0.006	0.77	0.73	279
Embodied product 9	0.39	0.12	1.49	0.14	0.15	0.21	0.003	0.003	S:0.068, Ca:0.0031, Zr:0.005	0.77	0.73	278
Embodied product 10	0.41	0.11	1.45	0.11	0.12	0.2	0.005	0.005	S:0.055, Mg:0.0025	0.76	0.73	278
Comparative product 1	0.3	0.1	1.5	0.1	0.1	0.2	0.004	0.021		0.72	0.62	254
Comparative product 2	0.54	0.11	1.43	0.11	0.11	0.21	0.005	0.022		0.82	0.86	309
Comparative product 3	0.41	0.75	1.42	0.08	0.09	0.2	0.004	0.021		0.86	0.76	260
Comparative product 4	0.41	0.12	2	0.1	0.1	0.2	0.004	0.018		0.9	0.81	290
Comparative product 5	0.42	0.15	1.5	0.15	0.15	0.75	0.003	0.023		1.34	0.87	383
Comparative product 6	0.41	0.12	1.43	0.12	0.11	0.21	0.015	0.02		0.77	0.73	279
Comparative product 7	0.42	0.25	1.53	0.23	0.22	0.45	0.003	0.021		1.06	0.85	329
Comparative product 8	0.35	0.1	0.8	0.05	0.05	0.45	0.004	0.022		0.83	0.59	295
Comparative product 9	0.4	0.11	1.45	0.1	0.1	0.19	0.005	0.021	Pb:0.32, S:0.21	0.75	0.71	273
Comparative product 10	0.41	0.09	1.4	0.09	0.09	0.18	0.004	0.023	S:0.215, Ca:0.032	0.73	0.71	271
Comparative product 11	0.4	0.1	1.48	0.1	0.1	0.21	0.005	0.021	Bi:0.31, S:0.051, Ca:0.0021	0.77	0.72	278
Comparative product 12	0.48	0.25	0.8	0.05	0.05	0.15	0.004	0.008		0.61	0.67	255

(Sectional Hardness)

Sectional hardness of the test pieces was measured by a 0.1 mm pitch in the depth-wise direction over an 1 mm depth from the component surface to the inner portion, using a Vickers hardness tester

5   under a load of 2.9 kN and a test period of 15 seconds.   It is noted herein that hardness of the real component surface cannot be measured, so that Vickers hardness measured at a position 50 μm deep from the component surface was assumed as the hardness of the component surface (depth=0 mm).

10

(Fatigue Property)

The test pieces were subjected to fatigue test using an Ono-type rotating-bending fatigue tester, and measured values of fatigue strength (MPa) were used as indices of fatigue property as component strength.

15

(Bend Straightening Property)

The test pieces were subjected to three-point bending test using a universal testing machine, wherein measured values of amount of indentation (mm) causative of cracks in the component surface were

20   used as indices of the bend straightening property.

Table 2 shows results of these measurements which include Vickers hardness at the surficial reference position (at a position 50 μm deep from the component surface), Vickers hardness at a position 0.3

25   mm deep from the component surface (referred to as "effective

hardening depth position", hereinafter), fatigue strength as an index of the fatigue property, and amount of indentation as an index of the bend straightening property.   It is to be noted that the individual measurements for the sectional hardness, fatigue property and bend straightening property were made using separate test pieces individually fabricated under the same conditions.

Evaluation was also made on the machinability in machining such as being carried out for fabricating the test pieces.   Steels having chemical compositions listed in Table 1 were melted similarly to as described in the above, hot-forged to thereby obtain rod-formed forged materials of 40 mm in diameter, kept under heating at 880°C for 60 minutes, and then normalized by allowing them to cool down to room temperature.   Machinability of thus-normalized products was evaluated by subjecting them to machining test using a carbide tool.   The machining test was carried out under a cutting speed of 200 m/minute, a feed speed of 2 mm/rotation and a cutting width of 2 mm, wherein cutting time elapsed before the wear width of the side clearance surface of the carbide tool reached 0.2 mm was measured.   Assuming now that measured cutting time of the normalized product corresponded to embodied product 1 as 100, based on which the measured values of the cutting time of the other normalized products corresponded to other test pieces were standardized and listed in Table 2 as cutting efficiency expressing the machinability.

Table 2

	Vickers hardness (HV)			Fatigue property	Bend straightening property	Machinability
	Surficial reference position	Inner portion	Depth of effective hardening	Fatigue strength (MPa)	Amount of indentation (mm)	Cutting efficiency
Embodied product 1	355	211	271	432	5.7	100
Embodied product 2	407	212	306	504	3.8	100
Embodied product 3	350	249	283	431	5.9	87
Embodied product 4	448	231	334	539	2.6	94
Embodied product 5	364	225	274	462	4.8	120
Embodied product 6	347	221	271	450	5.7	853
Embodied product 7	375	220	282	445	4.5	723
Embodied product 8	369	225	277	448	5.2	1065
Embodied product 9	365	224	275	433	5.2	1002
Embodied product 10	367	220	278	434	5.3	913
Comparative product 1	357	188	246	390	5.1	125
Comparative product 2	388	252	305	491	4.2	68
Comparative product 3	402	224	264	398	3.8	92
Comparative product 4	—	—	—	—	—	—
Comparative product 5	586	265	391	617	0.5	78
Comparative product 6	471	212	273	447	1.5	100
Comparative product 7	482	249	337	551	0.8	86
Comparative product 8	385	185	296	398	3.8	145
Comparative product 9	364	211	273	413	5.1	212
Comparative product 10	360	220	271	415	4.7	1680
Comparative product 11	375	221	278	421	4.1	1129
Comparative product 12	296	206	249	358	6.3	103

As shown in Table 1 and Table2, embodied products 1 to 10 showed values of Vickers hardness at the surficial reference position of 340 to 460 HV, Vickers hardness of the inner portion of 190 to 260 HV, and Vickers hardness at the effective hardening depth position of 270 HV or above.   They were confirmed to be excellent both in the fatigue

property and bend straightening property. It is to be noted herein that in the present embodiment, the mechanical components excellent both in the strength and bend straightening property are defined as those having a fatigue strength which gives an index of fatigue property of 400

5 MPa or above, and an amount of indentation which gives an index of bend straightening property of 2 mm or more. In the steel compositions listed in Table 1, the residual portion other than those listed therein is essentially composed of Fe.

On the contrary, comparative product 1 showed a hardness of the

10 inner portion of less than 190 HV, and a hardness at the effective hardening depth position is less than 270 HV, although the hardness at the surficial reference position was maintained at 355 HV. This consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as

15 compared with that of the embodied products, in other words, this failed in obtaining a desirable level of component strength. As discussed from the viewpoint of steel composition, comparative product 1 has C[eq.] smaller than that of the embodied products, due to the C content. The present embodiment adopts process conditions (process

20 temperature, process time) of nitriding which fall in general ranges, and this reaches a conclusion that C[eq.] is preferably adjusted to 0.65 or more in view of reliably adjusting hardness at the surficial reference position and at the effective hardening depth position to desirable levels, and raising the hardness of the inner portion, which is necessary for

25 ensuring a sufficient level of the component strength. As for the C

content, it is preferably adjusted to 0.35 wt% or more (see embodied product 2).

Next, comparative product 8 showed a hardness of the inner portion of less than 190 HV, and showed hardness both at the surficial reference position and at the effective hardening depth position of the desired levels, but a reduction rate of the hardness towards the inner portion was high similarly to comparative product 1, and this consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 8, C[eq.] is preferably adjusted to 0.65 or more in view of reliably raising the hardness of the inner portion, which is necessary for ensuring a sufficient level of the component strength, based on the same reason with comparative product 1.

Comparative product 3 showed desirable level of hardness values at the surficial reference position and of the inner portion, but showed a hardness at the effective hardening depth position of less than 270 HV, proving a large reduction rate of the hardness towards the inner portion, and this consequently resulted in only an insufficient surface hardness of the surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 3, it can be said that the reduction rate of the hardness towards the inner portion was excessively increased because the Si content

thereof became excessively large as compared with those of the embodied products. In view of reliably raising the hardness at the effective hardening depth position necessary for ensuring a sufficient level of the component strength, the Si content is preferably adjusted to

5   0.3 wt% or less (see embodied product 2), for example.

Comparative product 12 showed a desired hardness for the inner portion, but showed hardness smaller than desired for the surficial reference position and effective hardening depth position. This consequently resulted in only an insufficient surface hardness of the

10   surficial portion, and in considerably lowered fatigue strength as compared with that of the embodied products. As discussed from the viewpoint of steel composition of comparative product 12, Cr[eq.] is preferably adjusted to 0.72 or more in view of reliably raising the surface hardness required for ensuring a sufficient level of the component

15   strength.

Comparative product 5 showed a hardness of the inner portion exceeding 260 HV, and a desirable level of hardness at the effective hardening depth position of as high as 270 HV, but also showed a hardness at the surficial reference position exceeding 460 HV. This

20   resulted in an excessively large surface hardness of the surficial portion, an amount of indentation considerably lowered from that of the embodied products, and consequently resulted in only an insufficient bend straightening property. As discussed from the viewpoint of steel composition of comparative product 5, the excessively large surface

25   hardness of the surficial portion was supposed to be ascribable to the

Cr[eq.] larger than that of the embodied products, due to the Cr content. Cr[eq.] is therefore preferably adjusted to 1.0 or less in view of reliably obtaining a desired level of surface hardness at the surficial reference position required for ensuring a sufficient level of bend straightening

5   property.   Another possible reason for the excessively large surface hardness was also supposed to be the large Cr content, which was ascribable to the large C[eq.] and the hardness of the inner portion larger than desired.   It is therefore preferable to limit C[eq.] to as low as 0.86 or less in view of reliably ensuring a sufficient level of bend

10   straightening property.   From the viewpoint of Cr content, it is preferably adjusted to 0.5 wt% or less (see embodied product 2) .

Comparative products 6 and 7 showed desirable levels of hardness of the inner portion and at the effective hardening depth position, but showed hardness values exceeding 460 HV at the surficial

15   reference position.   This resulted in an excessively large surface hardness, an amount of indentation considerably lowered from that of the embodied products, and consequently resulted in only an insufficient bend straightening property.   From the viewpoint of steel composition, comparative product 7 was supposed to be excessively raised in the

20   surface hardness of the surficial portion due to Cr[eq.] larger than that of the embodied products.   It is therefore preferable to limit Cr [eq.] to 1.0 or less in view of reliably obtaining a desired level of hardness at the surficial reference position required for ensuring a sufficient level of bend straightening property.   Comparative product 6 was supposed to

25   be excessively raised in the surface hardness due to an excessively

large Al content.   It is therefore preferable to limit the Al content to 0.01

wt% or less (see embodied product 3) in view of reliably obtaining a

desired level of bend straightening property.

Next paragraphs will describe the machinability.   Comparative

5   product 2 was found to be excellent both in the component strength and

bend straightening property, but suppressed in the machinability due to

a large C content.   For the case where there are demands for an

improved machinability, and for both of excellent component strength

and bend straightening property, it is therefore preferable to limit the C

10   content to, for example, 0.5 wt% or less (see embodied product 3).

Embodied products 5 to 10 contain any one or more of Pb, S, Ca, Bi, Ti,

Zr and Mg which are machinability-improving elements.   Embodied

products 5 to 10 are thus successfully raised in the machinability as

compared with the others.   Addition of the machinability-improving

15   elements to the steel composition is understood as an effective measure,

because suppression of the machinability may sometimes result in the

component strength.   It was found from comparison, for example,

between embodied products 1 and 6 that the both showed an equivalent

amount of indentation, but embodied product 6 containing the

20   machinability-improving elements certainly showed a larger fatigue limit.

Also comparative products 9 to 11 were found to be excellent

both in the component strength and bend straightening property,

similarly to the embodied products.   The machinability-improving

elements are contained in these steel compositions.   The fatigue limit

25   as an index for the component strength was, however, conversely

lowered from those of the embodied products, due to large contents of these machinability-improving elements. It is therefore preferable to limit the contents such as Pb: 0.30 wt% or less, S: 0.20 wt% or less, Ca: 0.01 wt% or less, Bi: 0.30 wt% or less, Ti: 0.02 or less, Zr: 0.02 wt% or

5   less and Mg: 0.01 wt% or less.

Comparative product 4 showed an excessive generation of bainite due to an excessively large Mn content in the steel composition. Comparative product 4 was found to be inappropriate as a product as early as when it was made into a forged material. It is therefore

10   preferable to limit the Mn content to 1.8 wt% or less.

From the discussion referring to Table 1 and Table 2, it was confirmed that adjustment of Vickers hardness individually at the surficial reference position, effective hardening depth position and inner portion so as to fall them within the optimized ranges of the present

15   invention is essential for making the component strength and bend straightening property excellent. Next, in relation to Claim 2, data obtained based on the above-described equation (1) will be shown in Fig. 3.

The individual data points in Fig. 3 express results of the

20   measurement of the sectional hardness of the representative test pieces, selected from those of the individual test pieces. The individual curves (broken lines) almost fitted to the individual data points were obtained based on the equation (1). It is obvious that the equation (1) is a good approximate expression based on a better reflection of the measured

25   values of the sectional hardness. As is clear from the drawing, the

sectional hardness reduces from the component surface towards the inner portion, and reaches plateau at the inner portion. It is to be noted herein that the inner portion is defined by a region 1 mm deep or more from the component surface. The individual curves based on the

5   equation (1) shown in the drawing are obtained under T=600°C, which corresponds to the nitriding temperature, and $t=7.2 \times 10^3$ seconds, which corresponds to the process time.

In Fig. 3, filled plots represent the embodied products, and blank plots represent the comparative products. A region surrounded by the

10   data points of the embodied products (vertical hatched region in the drawing) is included in region Z defined by using the equation (1). More specifically, further increase in the process temperature and process time of the nitriding for embodied product 1 results in increase in the sectional hardness so as to come closer to that of embodied

15   product 4. On the other hand, decrease in the process temperature and process time of the nitriding for embodied product 4 results in decrease in the sectional hardness so as to come closer to that of embodied product 1. It is accordingly obvious that adjustment of the measured hardness distribution profile so as to fall within region Z

20   defined by using the equation (1) makes the mechanical component excellent both in the component strength and bend straightening property. A numerical range of H'1 in the equation (1), expressing hardness at the surficial reference position, is based on Cr[eq.], showing a range of Vickers hardness defined thereby from 348 HV to 458 HV, and

25   on the other hand, a numerical range of H'0, expressing hardness of the

inner portion, is based on C[eq.], showing a range of Vickers hardness defined thereby from 199 HV to 252 HV.   In other words, by making the measured hardness distribution profile fall within the region Z defined by the equation (1), both of the component strength and bend straightening

5   property are made excellent.   It is made possible to obtain desired levels of component strength and bend straightening property by appropriately varying the hardness distribution profile within the region Z.

The above-described results proved that the effects and desired

10   ends of the present invention can successfully be achieved.   It is to be noted that the above-described embodiment and examples are only for the purpose of exemplification, by which the present invention is never limited, allowing any modifications to be included within a concept of the present invention without departing from the description of the claims.

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